EcoSmart™ Concrete Project
A Concrete Contribution to the Environment™

THE LO RESIDENCE
CASE STUDY

THE USE OF HIGH VOLUME FLY ASH CONCRETE
AT THE LO RESIDENCE

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1.0 EXECUTIVE SUMMARY

This report details The Haebler Group's use of EcoSmart™ concrete in the construction of the Lo Residence, a single-family house located in the Endowment Lands at the University of British Columbia, Vancouver, British Columbia. The design featured EcoSmart concrete primarily because of its aesthetic appeal. This project was chosen as a case study for EcoSmart in part because of its use of high volume fly ash (HVFA) concrete in horizontal applications.

EcoSmart concrete was used successfully in both horizontal and vertical applications, although, for the HVFA mixes used in this project, the actual quantity of total cementitious material was increased over conventional mixes with a similar strength. Further, the HVFA concrete used on this project was found to have a slower set time and higher slump, increasing the wall form pressures and causing slab finishing delays. Since premium form design was already incorporated into the construction budget, the extra precautions taken in the wall form design and construction did not increase the cost of the vertical elements. However, the longer set times did increase the slab finishing costs. Offsetting these costs were the cost savings realized by eliminating sandblasting and other surface finishing because of the excellent quality of "form fresh finish" in the finished wall surface. The cost of the HVFA mix for the vertical applications was equivalent to comparable Type 10 Architectural Quality mixes. In contrast, the HVFA mix used in horizontal applications resulted in a cost premium over standard slab mixes because of the increased strength of the HVFA mix.

The most noticeable cold weather concreting problem was darkening and discolouration of the finished and exposed surface. Otherwise, the use of HVFA concrete resulted in a fine, dense surface texture, and light colour consistently throughout construction. The Haebler Group will continue using the HVFA mix in applications where a high quality concrete finish is required.

2.0 PROJECT DESCRIPTION

2.1 Project Overview

The Lo Residence is a new single-family house, situated in the University Endowment Lands at UBC, Vancouver, British Columbia. The house is a unique, architecturally designed structure that utilizes exposed concrete, glass, and a zinc clad, plywood faced, stressed skin roof, as its main design elements.

The Haebler Group was retained as the general Contractor early in the design process. Actually there really was no design, only a model, when the Owner and architect retained The Haebler Group. The Architect, Bing Thom, wanted a structure that had high quality exposed concrete as its major feature. The Haebler Group are well known as contractors who can produce high quality projects under demanding design conditions, and had worked with the Architects before on a similar project.

The exposed concrete was expected to have both exterior and interior applications. The architect's first choice was to utilize white cement concrete. This was for a number of reasons. Firstly white cement concrete has a lighter colour than normal Type 10 Portland cement concretes. Secondly, and possibly more importantly, white cement concrete tends not to darken when it gets wet. While this is only a temporary feature of normal exposed concrete (that it darkens when it gets wet), in the west coast rain forest environment of Vancouver, this is a feature that can occur quite often.

2.2 Project Team

Client:	Lo Family
Architect:	Bing Thom Architects Inc.
Structural Engineer:	Fast & Epp Structural Engineers
Materials Engineer:	AMEC
Contractor:	The Haebler Group
Concrete Supplier:	Ocean Construction Supplies Ltd.

2.3 Project Details

Location:	University Endowment Lands, UBC, Vancouver BC
Concrete Construction:	June – December 2002
Completion Date:	June 2003
Building Area:	850 m^2
Size of Structure:	2-storey house, with full basement, and detached garage

3.0 USE OF ECOSMART™ CONCRETE

3.1 Goals

During the design development stage, The Haebler Group submitted a number of concrete samples, from normal Type 10 cement based concrete mixes, to white cement mixes, to Titanium admixture based mixes, to a number of oxide based mixes. Also submitted was a High Volume Fly Ash Concrete (HVFA) sample based on a mix The Haebler Group had used on a previous project, The Waterfall Building, located at 1540 West 2nd in Vancouver, B.C. All the mixes submitted were from one supplier, Ocean Concrete Supplies of Vancouver B.C. The samples were reviewed based on a smooth plain surface finish, and a sandblasted finish.

After much deliberation and discussion the HVFA mix was selected. The reasons were both economic and aesthetic. The HVFA mix is economic because the cost of the HVFA mix is similar to high end “grey” cement based mixes (normal Type 10 Portland cement). Since the construction budget was based on a high end “grey” architectural concrete mix there was no cost implication to using the HVFA mix (there would have been a significant cost implication going to “white cement” based mixes). The aesthetic reason was based on colour and texture. The HVFA mix has a much lighter colour than conventional normal Type 10 mixes, and the architect preferred the colour and texture of the HVFA mix compared to conventional “grey” mixes. The reason HVFA mixes have a lighter colour is due to the large amount of Fly Ash used in the mix. The author does not know if different types of Fly Ash vary in colour. Certainly the Fly Ash used by Ocean Concrete (Type F) produces a mix which is much lighter in colour than a normal Type 10 based concrete, approximately mid way between a “grey” cement mix and a white cement mix. It is interesting to note that the environmental benefits of HVFA concrete were not considered in the selection.

Another feature of the HVFA concrete, which was interesting to note, was that it did not appear to darken as readily as the normal "grey" mixes reviewed when it became wet. This could well be due to the higher impermeability the HVFA mixes have been tested to have, as well as denser surface textures that our experience has shown.

This report will not delve into the technical attributes of HVFA concrete. For that we refer the reader to another case study report written by the author and Michael Neudorf entitled, "High-Volume Fly Ash as a Supplementary Cementing Material: A Case Study: Arthur Erickson designed Artist Live Work Studios, 1540 West Second, Vancouver B.C.", which can be found at www.ecosmart.ca. That report touches on the technical, environmental, physical and economic uses of this Fly Ash, and HVFA concrete in general.

3.2 Project Chronology

The Lo Residence construction started in May 2002, with concrete work taking place between June 2002 and December 2002. The climate in Vancouver is much more temperate than in other parts of Canada, however we did have an unusually colder fall, and early winter than in previous years. Table 1 lists the average, high and low temperatures during the period in which concrete was poured. Concrete pours generally took place in the morning, or midday periods.

Table 1: Average, High and Low Temperature during Concrete Pours

	June	July	August	Sept	Oct	Nov	Dec
Avg	16.1	18.0	17.9	15.0	9.7	7.7	5.3
High	30.2	28.0	27.1	23.9	16.3	17.0	13.5
Low	7.6	8.5	11.0	7.1	-1.9	-3.7	-1.8

Temperature data obtained from Environment Canada Climate Services, 1-900-565-1111.

3.3 Concrete Mix Design

The structural engineer for this project was Fast & Epp Structural Engineers. They were also the engineers for The Waterfall Building and were familiar with the HVFA concrete used on that project. The structural specifications for the Lo Residence project required a concrete that achieved a 30 MPa compressive strength in 28 days for Walls, Columns, and Slabs.

The mix selected from the samples was Ocean's HC1 mix. This was a mix that was based on the original HVFA test mix used at the Liu Centre for the Study of Global Issues building at UBC in 1999. The Liu Centre was a project built in 1999 by The Haebler Group that was the first project to utilize HVFA concrete. Phil Seabrook of Levelton Engineering, a consulting materials engineer in Vancouver, in conjunction with John Rutherford of Ocean Concrete, and CANMET, developed the Liu Centre mix. This original mix only achieved a 25 MPa at 28 days designation. However, as a result of the successful tests and usage at the Liu Centre, and with a few modifications, Ocean Concrete, the ready mix supplier agreed to modify the strength designation to 30MPa at 56 days for the mix that was used at The Waterfall Building. Since it is now accepted by many engineers to consider 56-day strengths for projects where the structure is not expected to experience design loads until well after the structure is completed, the 56-day designation was specified by the structural engineers for this project.

An interesting characteristic of the HVFA mixes used in this project is that the actual quantity of total cementitious material is increased over conventional mixes with a similar strength. A review of Table 2 will show a comparison between the selected mix for this project, compared with the HVFA mix used for The Waterfall Building, and compared again to standard 30 MPa and 40 MPa mixes. As was discussed in the Waterfall Building report, the HVFA mixes used by Haebler Construction still contain more total cementitious material than comparable standard mixes of a similar strength. The reason for this has to do primarily with the fact that the HVFA mixes used by Haebler Construction needed to achieve certain aesthetic requirements. Future studies should be made using mix designs that contain a total cementitious quantity approaching that of conventional mixes of a similar strength.

Table 2: Comparison of Lo Residence Case Study Mix to Other Mixes

	Lo Residence Case Study 30 MPa @ 56 days	The Waterfall Building 30 MPa @ 28 days	Standard 30 MPa @ 28days	Standard 40 MPa @ 28 days
Cement	195kg	195kg	240kg	310kg
Fly Ash	195kg	195kg	65kg	80kg
Total Cementitious	390kg	390kg	305kg	390kg

Test pours were made on site using a variety of form plywood, and with slight modifications to the actual mix. Different types of Form Plywood will produce variations in the finished surface. After about 10 test pours it was decided to use a modified HC1 mix that used a water reducing agent, as well as to utilize 14mm pea gravel type aggregate in lieu of the normal 20mm crushed stone, along with a High Density Overlay Plywood as the form surface.

The test pours indicated that using the smaller aggregate produced a finer and denser surface finish. As well, since many of the exposed walls would be 12" thick, with 4" of rigid insulation in the center, it was felt that utilizing a mix with a smaller aggregate would make the pouring process easier and improve the consolidation of concrete around the reinforcing steel. However, as will be seen in Table 2, using the 14mm aggregate was most likely the reason why the Lo Residence mix did not achieve as high compressive strength test results as previous HVFA mixes. This is because much of the compressive strength of concrete is directly related to the strength of the coarse aggregate.

The test pours were such a success, especially utilizing the high density overlay plywood, that it was decided to delete the originally specified sandblasting and to keep the concrete surface "Form Fresh". Deleting the sandblasting resulted in a further labour and material cost saving, that was achievable only by utilizing the HVFA mix.

Figure 1 shows the first test pour, with 3 different plywood surfaces. The panel at the right utilized high density overlay plywood, and it can be seen that it provides a lighter coulured surface finish. The panels at the left utilize medium density overlay plywood. Figure 2 shows a portion of the exposed walls above grade that will remain part of the finished project. This surface is a "as cast" surface, with no patching or remedial work having been done.

Figure 1: Initial Test Wall Showing 3 Plywood Surfaces

Figure 2: View of Exposed Section of Basement Wall

3.4 Concrete Use in Structure

Originally HVFA concrete was to be used strictly for the exposed vertical walls and columns, which represented about 42% of the total volume of concrete used in the house. However because of the numerous test pours, and since the EcoSmart™ Concrete Project was willing to collaborate on some test work using HVFA concrete for horizontal slab pours as well, 100% of the concrete above the footings and Slab on Grade was achieved utilizing HVFA concrete.

3.5 Findings

3.5.1 Strength

As mentioned previously the original concrete specification required a 30MPa at 28 days compressive strength for all the concrete utilized, which was later changed to a 56-day strength. Additionally concrete utilized for exterior applications required a F2 classification. Even though the HVFA mix selected did not have a formal F2 classification under the CSA 23.1 specification, because of the work done by others, namely Phil Seabrook, and others at the EcoSmart Concrete Project, it has been accepted that the HVFA concrete is suitable for exterior applications.

The actual test results for all concrete tested using the HVFA mix are shown in Appendix A. Figure 3 shows a summary of the results compared to the HVFA mix used at The Waterfall building. As can be seen the average maximum values for the Lo Residence mix achieved lower strength characteristics than the initial HC1 mix. Since the strength in any concrete mix is in large part related to the strength of the aggregate, the author suspects that it was the use of the 14mm aggregate for aesthetic reasons that resulted in this lower strength. However, the actual test results do show that even the minimum test results are above the specified 30MPa at 56 days requirement.

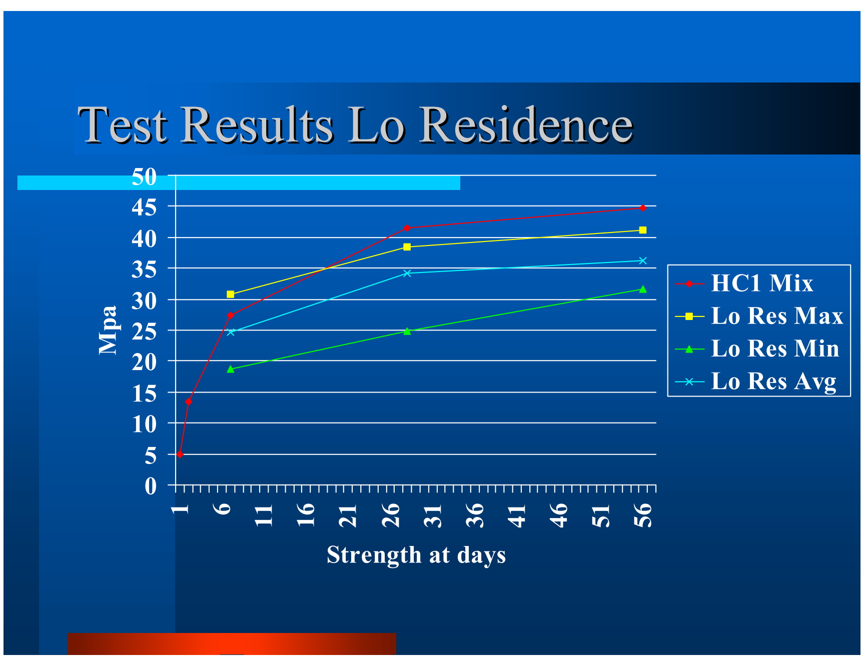

Figure 3: Test Results of Lo Residence HVFA Mix as Compared to HC1 Mix

3.5.2 Vertical Wall Pours

Because of the high quality exposed surface demanded by this project, extra precautions were taken in the form design to ensure a high quality product. Forms were constructed with 4x4 studs and wailers, spaced closely together, and 2 layers of plywood were utilized as the form liner to minimize deflection between supports. In addition all plywood panel joints were caulked on the edges to eliminate bleeding, which causes discoloration in the poured surface.

These precautions are especially important in HVFA concrete applications due to the slower set time of these mixes compared with more conventional Type 10 cement mixes. In addition, because of the addition of the superplastizer the mixes used in this project had a high initial slump. This higher slump had a number of benefits; aiding in reducing voids under window bucks, helping to reduce air entrapment, and reducing the need for excessive vibration during pouring. However because of the higher slump, an increase is realized in the liquid head pressures being exerted on the forms, and thus it is important to have particularly strong forms and tight joints to avoid bleeding.

As has been mentioned by the author in previous reports and presentations, HVFA concrete does not appear to produce acceptable curing and aesthetic qualities in cold weather conditions. This is related to a number of factors. Firstly, because of the high amount of fly ash in the mix, the HVFA mix will set up much slower than conventional mixes. Secondly, there appears to be a tendency of the HVFA to bleed more water to the surface of the form, which in some way results in a stained surface texture.

This feature of HVFA not producing acceptable curing and aesthetic qualities in cold weather applications has also been discussed by others, namely Architect Peter Busby discussing his project in the Nicola Valley of British Columbia. However in that project the problems related more to extended set times since there was no real “architectural” or exposed element that was being considered.

Figure 4 shows an example of this discoloration, this being the spandrel beam which was poured in November well after the main house portion on the left, or the garage portion on the right. Note that temporary heat was utilized on the panel on the right for 3 to 4 days and some lightening of the concrete occurred. We are therefore hopeful that the colour will lighten more once the concrete warms up in the summer.

Figure 4: Discolored HVFA Concrete Panel Poured during Cold Weather Period

3.5.3 Horizontal Pours

One of the reasons this project was selected as a case study was the request from the EcoSmart Concrete Project to undertake testing using HVFA concrete for horizontal applications. Previously HVFA concrete had almost exclusively been used in vertical wall and column applications. For the Lo Residence, HVFA concrete was used for the main and second floor suspended slabs. Not only were there exposed top surfaces in these pours, but also both slab edge and soffit elements as can be seen in Figure 4 above were utilized within the design as exposed features. For this reason extra precautions such as very strong forms utilizing 2 layers of plywood, strongbacks spaced no more than 8" apart, and heavy duty coil ties were utilized in the form design and construction. A total of 3 separate slab pours were required because of steps in the slab on the main floor. Slab pours occurred in August and September, all during fine weather periods.

Again high slump and plasticity helps in the placement of the concrete, by prolonging the period of workability, and aids in achieving a good smooth surface due to the ease at which paste can rise to the surface. The average slump of the mixes we used was 100mm. However there was also an increase in the set up time required before finish trowleing could take place. This is because of the increase set time of HVFA concrete. For this project we found that we would have to wait an additional 1 to 2 hours before finishing of the slab could take place. This had the unfortunate result of increasing the slab finishing costs by 15% to 25% due to the extended labour required.

3.5.4 Economics

Another factor which has to be considered when discussing using HVFA concrete for horizontal surfaces is cost. The specified mix for slabs was 30MPa. However standard 30MPa "grey" cement mixes cost less than the HVFA mixes considered in this project, which approach 35MPa mixes in the Vancouver market. Therefore a cost premium of approximately \$12.00/m^3 was experienced utilizing HVFA concrete over standard slab mixes. While it is interesting and environmentally positive to have a project in which all the concrete is HVFA concrete, one has to consider the cost.

The fact that there is a slower set time may have other benefits regarding crack reduction, durability of surface, etc, but this report will not attempt to address those issues.

Following are some photographs showing the process utilized for the horizontal pours. Figure 5 shows the crew poring the concrete with the bucket. All concrete used at the Lo Residence was poured with a crane-mounted bucket. Figure 6 presents a close up showing the paste rising very quickly.

Figure 5: Pouring First Slab with Concrete Bucket

Figure 6: Close-up during Vibration

Figure 7: Screeding the Concrete

Figure 8: Power Trowel Finishing the Concrete

4.0 CONCLUSIONS AND RECOMMENDATIONS

High Volume Fly Ash Concrete was utilized for this project solely based on its aesthetic qualities. These qualities are primarily a concrete with a fine, dense surface texture, and light colour.

It was demonstrated that it could be utilized effectively for both vertical wall pours and horizontal slab applications. Excellent results were obtained in the finished wall surface, and cost savings were realized by eliminating sandblasting and other surface finishing because of the excellent quality of "form fresh finish".

However extra precautions must be taken in the wall form design and construction, increasing the cost over conventional forms, to minimize deflection of the plywood, and leakage around joints, due to the higher liquid head pressures realized with the HVFA concrete used on this project due to its slower set time and higher slump.

While the environmental benefits of using fly ash, which would otherwise be a waste product, are appreciated, the HVFA mix used still represents a cost premium over conventional Type 10 cement equivalent strength concrete mixes. This is due to the high quality finish required on this project. However the mix design utilized for this project for vertical applications was at an equivalent cost to comparable Type 10 Architectural Quality mixes.

No appreciable cost premium was realized in form design, or in wall placing costs for this project, since the construction budget already contained an allowance for premium form design. However some increase in slab finishing costs was required, due to the longer finishing times required.

Continued problems seem to occur with the surface finish of HVFA concrete mixes when used in cold weather periods. The most noticeable problem is a darkening and discolouration of the finished and exposed surface, which was immediately noticeable once the forms were removed. We are hopeful that once the concrete warms up in the spring some of this darkened concrete will lighten in colour.

However overall all participants are extremely pleased with the finished product, and the mix will continue to be utilized by The Haebler Group in future projects where a high quality concrete finish is required.

Appendix A

Summary of Concrete Test results

set #	7-day	28-day	56-day
123	25.2		
122	31.8		
121	26.4	38	
120	30.8		
118	27.6	24.9	
117	26.4	38.5	
		37.3	
		37.9	
116	26.1	32.6	
	25.2		
	25.4		
115	22.7	34.7	38.7
114	25.7	34.2	39.5
			37.3
			38.4
113	22.4	33.3	35.3
			36.8
			36
112	23.9	35.5	36
			35.8
			35.9
111	22.2	26.9	31.6
			31.8
			31.7
110	24.4	37.3	39.5
			41.2
			40.3
109	23.4	34.3	36.8
	22		37.7
			37.3
106	23.2	34.3	
		35	
		34.7	
105	21.2	31.8	33.1
102	18.7	32.1	35.3
			34
			34.7
average	24.7	34.1	36.3
max	30.8	38.5	41.2
min	18.7	24.9	31.6

Appendix B
Selected Photographs


Figure B-1: South Wall


Figure B-2: View of East Walls

Figure B-3: Close-up of Form Fresh Finish, Wall and Slab Edge Cold Joint

Figure B-4: View during Ground Floor Construction